An Introduction to the Transformational Tools & Technologies (T³) Project

NASA Ames Research Center
September 25, 2014

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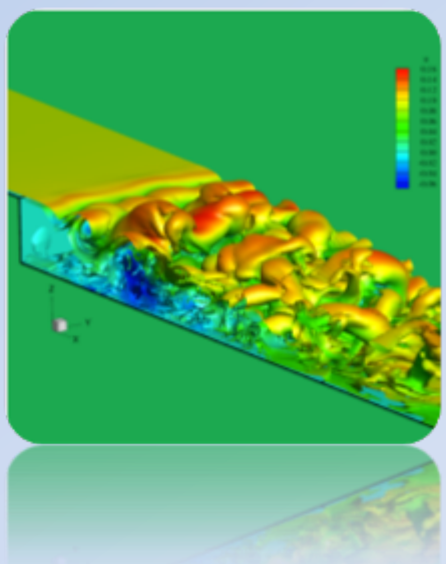
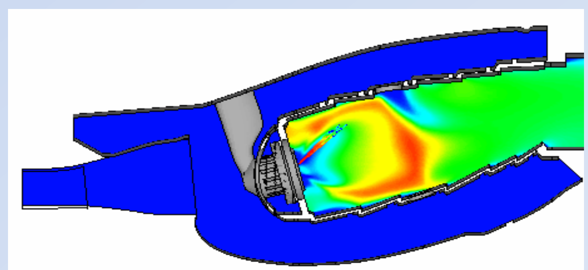
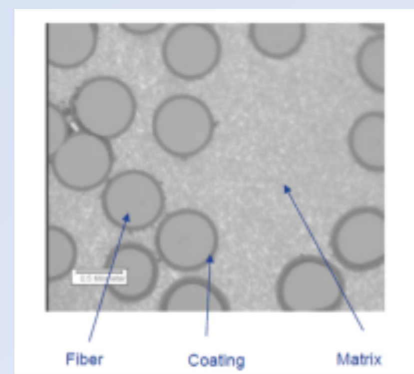






Why a new aeronautics research strategy?

Now is the time to lay the groundwork for the next 100 years of excellence.

- NASA Aeronautics has solid partnerships, high relevancy, and is delivering high impact
- But need to recognize:
  - Rising competition in international R&D
  - Challenges in mobility, energy and climate
  - Opportunities to infuse rapidly advancing non-aerospace sector technologies
- ARMD's new strategy builds on current leadership and focuses on enabling revolutionary advances

"Civil aviation [is] blessed with growing demand, record orders and increasing deliveries, but facing global competitors, affordability and sustainability challenges, and an industry-shaking technological revolution."

Graham Warwick,
AvWeek, September 2013

The Time Bomb of Complacency – AvWeek Editorial, September 2, 2013

"An alarm needs to be sounded. A vital and vigorous aeronautics research program is essential… NASA's unveiling of a new strategy for aeronautics research is a bold and welcome move."

NASA Aeronautics Research Six Strategic Thrusts

Safe, Efficient Growth in Global Operations
- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft
- Achieve a low-boom standard

Ultra-Efficient Commercial Vehicles
- Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion
- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Real-Time System-Wide Safety Assurance
- Develop an integrated prototype of a real-time safety monitoring and assurance system

Assured Autonomy for Aviation Transformation
- Develop high impact aviation autonomy applications

What's at the center of the reorganization?

The Promotion of Innovation and Convergent Research.

Goal 1: Pursue Innovative Solutions Aligned to the Strategic Thrusts

Enable programs to clearly define most compelling technical challenges and retire them in a timeframe that is supportable by stakeholders and is required by our customers.

Addressed through the formation of three Mission Programs and the integration of safety research throughout all programs.

- Airspace Operations and Safety Program
- Advanced Air Vehicles Program
- Integrated Aviation Systems Program

Goal 2: Incentivize Multi-Disciplinary "Convergent" Research

Establish a flexible and organic environment to allow for the development of high-risk, leap-frog ideas to address "big problems." This will allow rapid demonstration of feasibility with high turnover rates, conducted in a convergent, multi-disciplinary, integrated manner.

Addressed through the formation of the Transformative Aeronautics Concepts Program

Goal 3: Enable Greater Workforce and Institutional Agility and Flexibility

- Enable more flexibility to embed flight research throughout research phases and bring back X-plane culture.
- Enable more agile research practices that combine high-fidelity simulation, ground testing, and flight research.

Addressed by embedding the Aeronautics Test facilities and aircraft into the Advanced Air Vehicles and Integrated Systems Research Programs.

How are the vision’s research thrusts used?

All of the new programs address more than one, or all, of the research thrusts.

MISSION PROGRAMS

Airspace Operations and Safety Program — AOSP

Safe, Efficient Growth in Global Operations

Real-Time System-Wide Safety Assurance

Assured Autonomy for Aviation Transformation

Advanced Air Vehicles Program — AAVP

Ultra-Efficient Commercial Vehicles

Innovation in Commercial Supersonic Aircraft

Transition to Low-Carbon Propulsion

Assured Autonomy for Aviation Transformation

Integrated Aviation Systems Program — IASP

Flight research-oriented, integrated, system-level R&T that supports all six thrusts

X-planes/ test environment

SEEDLING PROGRAM

Transformative Aeronautics Concepts Program — TACP

High-risk, leap-frog ideas that support all six thrusts

Critical cross-cutting tool development

What is the Transformative Aeronautics Concept Program?

While mission programs focus on solving challenges, this program focuses on cultivating opportunities.

Seedling Program

Transformative Aeronautics Concept Program

Cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation and harnesses convergence in aeronautics and non-aeronautics technologies to create new opportunities in aviation

Knocks down technical barriers and infuses internally and externally originated concepts into all six strategic thrusts identified by ARMD, creating innovation for tomorrow in the aviation system.

Provides flexibility for innovators to explore technology feasibility and provide the knowledge base for radical transformation.

Solicits and encourages revolutionary concepts

Creates the environment for researchers to become immersed in trying out new ideas

Performs ground and small-scale flight tests

Drives rapid turnover into new concepts

Projects

Cross Program Operations

Leading Edge Aeronautics Research for NASA

Transformational Tools & Technologies

Convergent Aeronautics Solutions

Transformational Tools & Technologies (T^3) Project

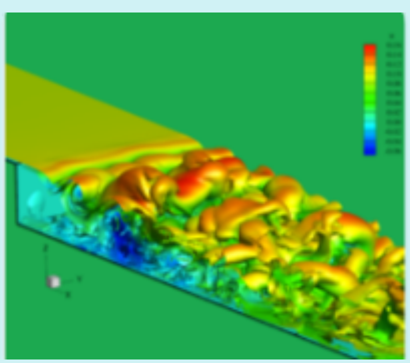
Enable fast, efficient design & analysis of advanced aviation systems from first principles by developing physics-based tools/methods & cross-cutting technologies, provide new MDAO & systems analysis tools, & support exploratory research with the potential to result in breakthroughs

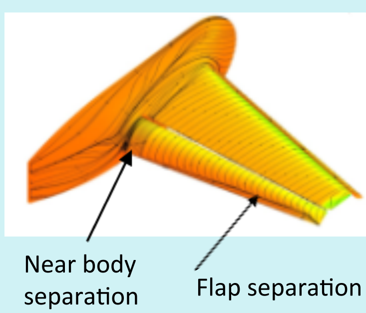
Vision

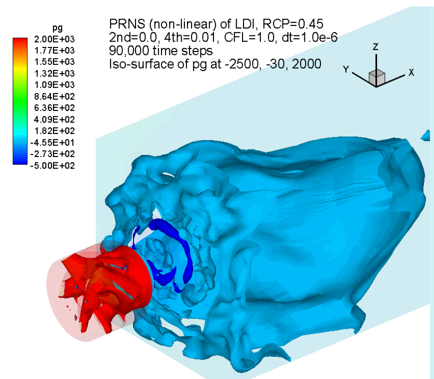
- Physics-based predictive methods for improved analysis and design
- Leverage improved understanding and discipline integration toward improved future air vehicles

Scope

- Foundational research and technology for civil air vehicles
- Discipline-based research and system-level integration method development







Transformational Tools & Technologies (T^3) Project

- New project under Transformative Aeronautics Concepts (TAC) Program
  - "Transformational Tools & Technologies" (T^3)
- Resources and content mapped directly from Aeronautical Sciences (AS) Project as starting point
- Must be responsive to SIP and 6 strategic thrusts as well as TAC and T^3 charter:
  - TAC -> Multidisciplinary revolutionary aviation concepts
  - T^3 -> Critical tools and methods to accelerate research and design of advanced concepts – also "technologies" such as critical materials/measurement/controls development
- Evaluate portfolio but envision small changes in FY15 content due to time constraints
  - Discuss potential realignment of content across ARMD projects
  - FY15 to be considered "transition year" to allow for ongoing portfolio assessment
  - Use FY15 to understand and advocate for more substantial changes in FY16+
  - Can potentially increase FTEs in FY16 under current PAA distribution

Aeronautical Sciences Project Organization

PROJECT LEVEL

- Organized by technical disciplines
- Technical leads for disciplines providing overall technical direction and oversight

Project Manager: Jim Heidmann (GRC)
Acting Deputy Project Manager: Dan Williams (LaRC)
Project Scientist: Mike Rogers (ARC)

Business Lead: Jacob Jevec (GRC)
Armstrong POC: Robert Navarro (AFRC)
NRA Manager: Julie Fowler (LaRC)
Scheduler: Joyce Moran (GRC)

ARC
Program Analyst:
Sandra Ramirez

AFRC
Program Analyst:
Becky Miani

GRC
Program Analyst:
Tom Halstead

LaRC
Program Analyst:
Julie Fowler

TECHNICAL DISCIPLINES

Discipline	ARC	AFRC	GRC	LaRC
Revolutionary Computational Aerosciences: Mujeeb Malik (LaRC)	RCA		RCA	RCA
Structures and Materials: Dale Hopkins (GRC)	SaM	SaM	SaM	
MDAO & Systems Analysis: Jeff Viken (LaRC)	MDAO	MDAO	MDAO	MDAO
Combustion: Jeff Moder (GRC)			Combustion	
Controls: Sanjay Garg (GRC)		Controls	Controls	Controls
Innovative Measurements: Tom Jones (LaRC)	Measurements	Measurements	Measurements	Measurements

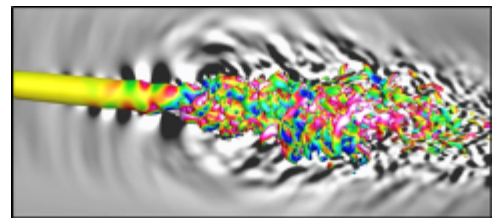
AS Research Themes, Tech Challenges

Research Themes	Technical Challenges 2013-2017
Revolutionary Computational Aerosciences	Identify and downselect critical turbulence, transition, and numerical method technologies for 40% reduction in predictive error against standard test cases for turbulent separated flows, evolution of free shear flows and shock-boundary layer interactions on state-of-the-art high performance computing hardware.
Structures and Materials	Develop high-temperature (2700 ^{o}F) materials for turbine engines that enable a 6% reduction in fuel burn for commercial aircraft, compared to current SOA materials.
	Additional Focus Areas 2013-2017
Structures and Materials	Development of improved multi-functional airframe and engine structures and materials and computational design and optimization capability.
MDAO and Systems Analysis	Tool development at multiple levels of fidelity for air vehicle design and analysis.
Combustion	Combustion physics-based modeling and fundamental experiments. Investigation of new combustor technologies.
Controls	Advanced control technologies to enable new capabilities for efficient and autonomous operation of aircraft and propulsion systems.
Innovative Measurements	New measurement technologies that support a range of other fundamental research needs.

Revolutionary Computational Aerosciences

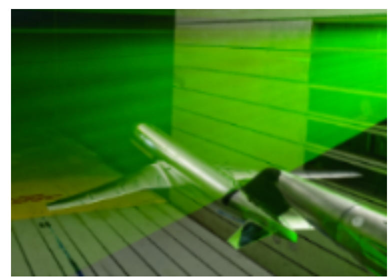
Objective

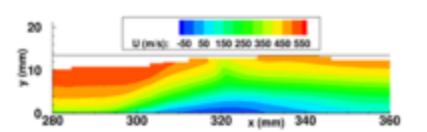
Identify and downselect critical turbulence, transition, and numerical method technologies for 40% reduction in predictive error against standard test cases for turbulent separated flows, evolution of free shear flows and shock-boundary layer interactions on state-of-the-art high performance computing hardware.



Technical Areas and Approaches

- Development of more accurate physics-based methods (e.g. higher moment closure, large eddy simulation (LES))
- Advanced numerical methods
- Transition prediction and modeling
- Validation experiments
- Multidisciplinary analysis and design (High Fidelity)





Benefit/Pay-off

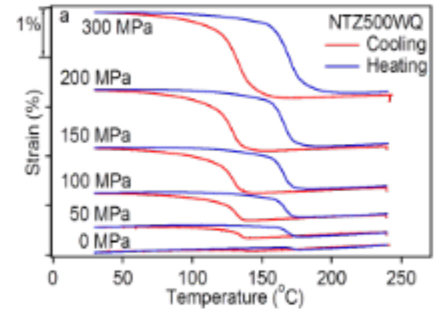
- Capability will be used by the aeronautics community to improve designs and reduce design cycle times
- Facilitates accelerated introduction of advanced air vehicles and propulsion systems into the airspace system.

Structures and Materials

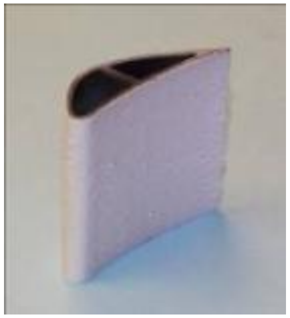
- Develop **multi-functional structures & materials** that reduce weight and enable innovative components by meeting multiple airframe or engine requirements simultaneously

- Develop **high temperature engine materials** and associated design and life prediction tools to reduce or eliminate the need for turbine cooling and reduce weight

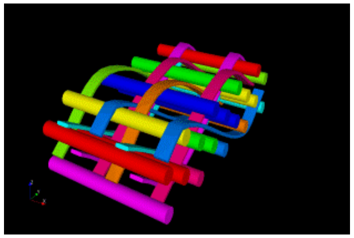
- Develop physics-based **computational design and optimization** capability for airframe and engine materials and structures



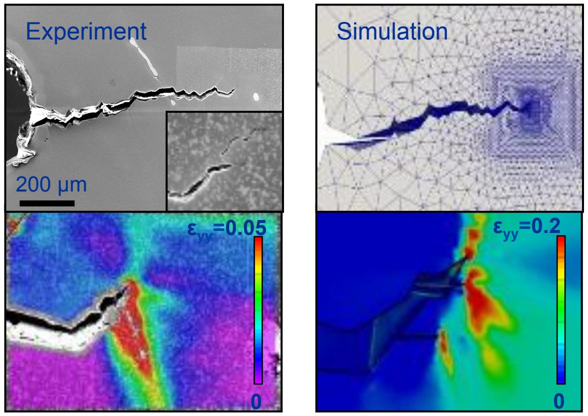
Shape-Memory Alloys



EBC-Coated CMC Vane



Advanced 3D Fiber Architecture

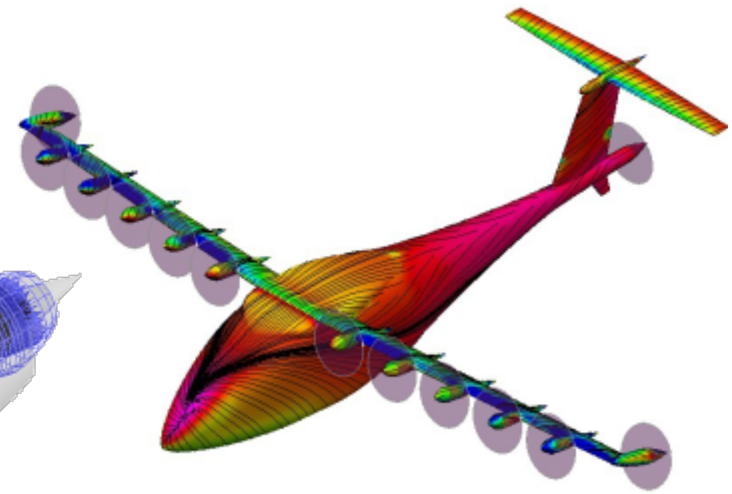


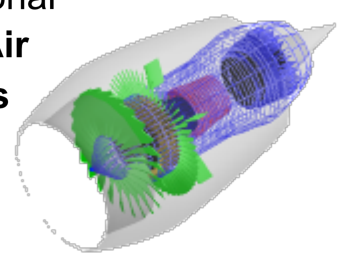
Computational Materials

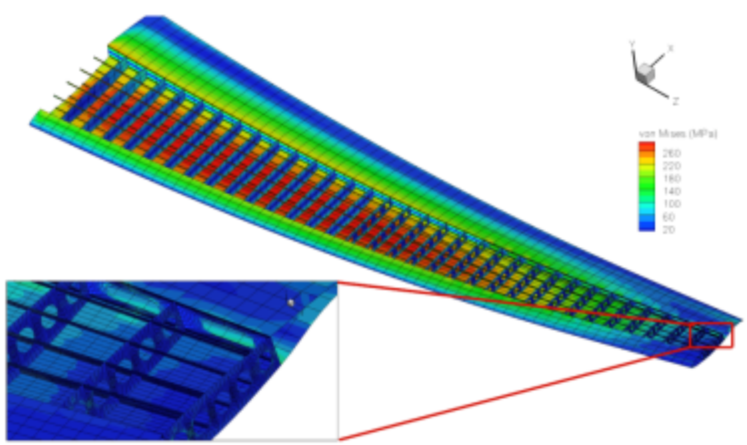
MDAO & Systems Analysis

Goal:

- Develop MDAO architectures and frameworks to solve complex optimization problems
- Improve upon the existing toolsets for the conceptual design and analysis of conventional and unconventional aircraft for **Advanced Air Vehicles and Transformative Aeronautics Concepts Programs** at NASA







Approach:

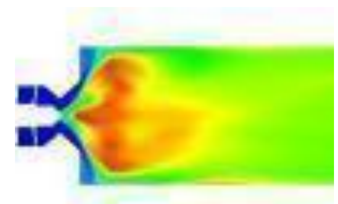
- Develop MDAO capabilities of the OpenMDAO framework and algorithm toolset
- Improve the flexibility and fidelity of parametric geometry modeling for input to high fidelity discipline tools
  - Conceptual design process
  - MDAO optimization capability
- Enhance and/or develop individual and multi-disciplinary tools at multiple levels of fidelity focused on conceptual design and analysis
- Use challenge problems to focus development and demonstrate capabilities

Combustion

Develop and validate physics-based combustion models, perform fundamental experiments and investigate new combustor technologies

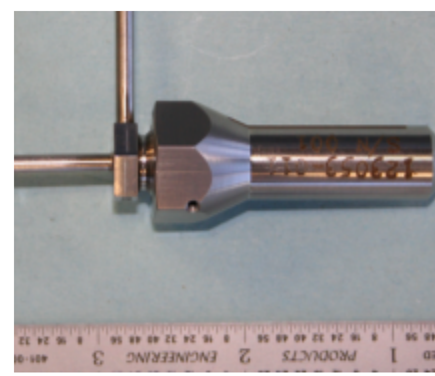
Goal

- Provide improved computational tools and critical technologies to enable combustor concepts that meet NASA fuel burn and emissions goals for future aircraft engines.



Approach

- Develop and validate physics-based combustion models for CFD. Develop capability for tightly coupled combustor-turbine simulations
- Perform experiments to provide high-quality CFD validation data at relevant combustor conditions (fuel, pressure, temperature)
- Perform experiments with detailed diagnostics to provide a fundamental understanding of low-emission systems
- Develop and test critical combustion control technologies (passive and active) for future lean burn combustors
- Explore innovative combustor technologies (such as Pressure Gain Combustion)

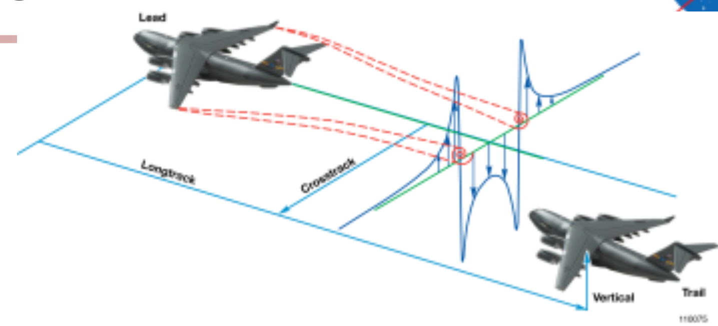


Controls

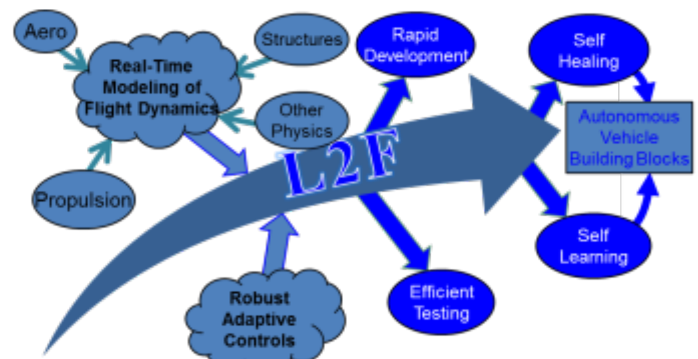
- **High Level Objective:** Develop advanced control technologies to enable new capabilities for efficient and autonomous operation of aircraft and propulsion systems

- **Advanced Flight Controls:**
  - Relative Navigation and Sensor Fusion for Cooperative Trajectories – AFRC
    - Overcome challenges to implementing cooperative trajectories for commercial aircraft operations
  - Learn to Fly – LaRC
    - Develop and validate tools and methods to enable rapid real-time development of vehicle models and self-learning design of control systems

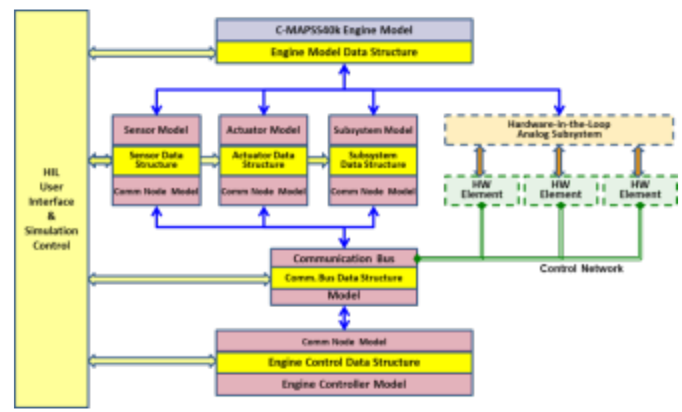
- **Advanced Propulsion Controls (GRC):**
  - Distributed Engine Control
    - develop and demonstrate technologies that will enable network based decentralized control architectures for turbine engine propulsion systems



Cooperative Trajectories



Learn to Fly Technology Roadmap

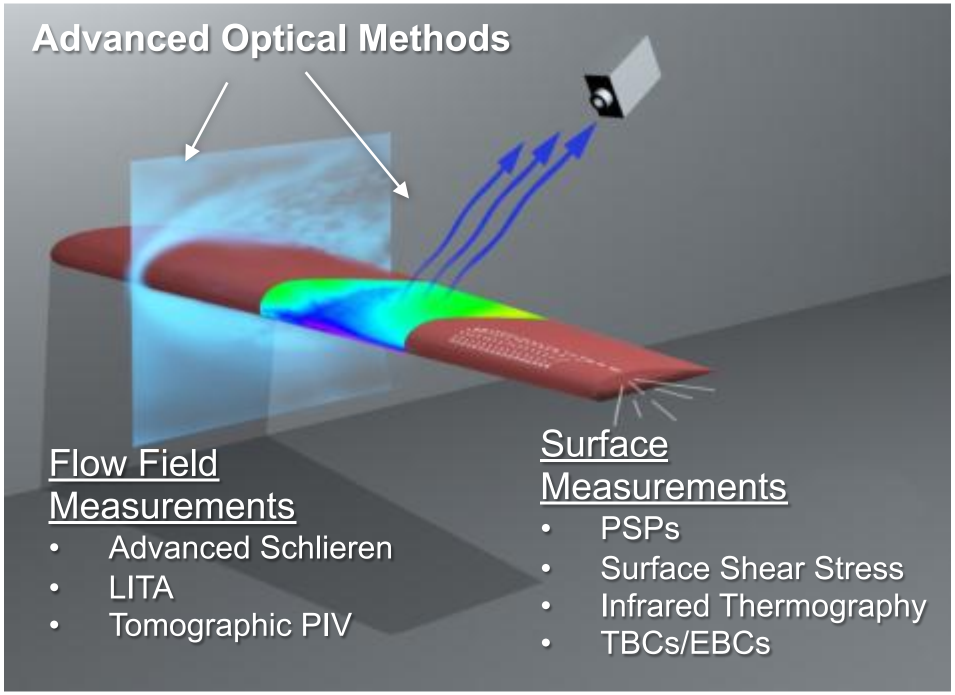


DEC Hardware-in-the-Loop Simulation Architecture

Innovative Measurements

PROBLEM
Measurement science technologies have limited fidelity robustness, range of applicability.

APPROACH
- Leveraging center expertise from all four research centers to produce integrated instrumentation approaches.
- Emphasize linkages/partnerships with other AS sub-projects and FA projects to fully establish the critical need for this work.
- Partner with ATP to coordinate investments.



SIGNIFICANCE
This will enable new methods for obtaining critical experimental data for validation of computational methods and for diagnostics of airframe and engine components.

Transformational Tools & Technologies (T^3) ARC FY15

T^3 Discipline	Activity	FTE Guideline
Project Management	**Associate Project Manager** **Project Analyst**	**0.6**
Revolutionary Computational Aerosciences	**Turbulence Modeling** **Numerical Methods**	**5.6**
Structures and Materials	**Shape Memory Alloys**	**0.0 (WYE Support)**
MDAO and Systems Analysis	**VIPER Framework**	**1.0**
Innovative Measurements	**Advanced Optical Measurements** **Enhanced Sensing**	**1.0**
Total T^3 Guideline		**8.2**

Vision 2030 Study

Advocacy Document for NASA-Led Analysis/Design Capability

- **"...Address(es) the long range planning required by NASA's Revolutionary Computational Aerosciences (RCA) sub-project, (which is managed under the Aeronautical Sciences Project) of the Fundamental Aeronautics Program (FAP)"**

"…provide a knowledge-based forecast of the future computational capabilities required for turbulent, transitional, and reacting flow simulations…"

"…and to lay the foundation for the development of a future framework/environment where physics-based, accurate predictions of complex turbulent flows, including flow separation, can be accomplished routinely and efficiently in cooperation with other physics-based simulations to enable multi-physics analysis and design."

CFD Vision 2030 Study Recommendations

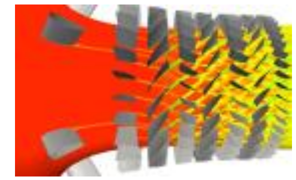
NASA should:

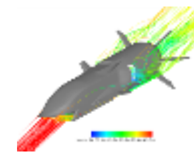
1. Develop, fund and sustain a base research and technology development program for simulation-based analysis and design technologies.
2. Develop and maintain an integrated simulation and software development infrastructure to enable rapid CFD technology maturation.
3. Make available and utilize HPC systems for large-scale CFD development and testing.
4. Lead efforts to develop and execute integrated experimental testing and computational validation campaigns.
5. Develop, foster, and leverage improved collaborations with key research partners and industrial stakeholders across disciplines within the broader scientific and engineering communities.
6. Attract world-class engineers and scientists.

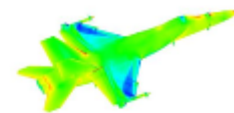
Report has been published as NASA-CR-2014-218178

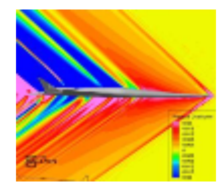
Vision of CFD in 2030

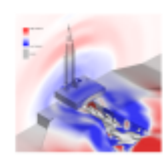
- Emphasis on physics-based, predictive modeling
  Transition, turbulence, separation, chemically-reacting flows, radiation, heat transfer, and constitutive models, among others.
- Management of errors and uncertainties
  From physical modeling, mesh and discretization inadequacies, natural variability (aleatory), lack of knowledge in the parameters of a particular fluid flow problem (epistemic), etc.
- A much higher degree of automation in all steps of the analysis process Geometry creation, mesh generation and adaptation, large databases of simulation results, extraction and understanding of the vast amounts of information generated with minimal user intervention.
- Ability to effectively utilize massively parallel, heterogeneous, and fault-tolerant HPC architectures that will be available in the 2030 time frame Multiple memory hierarchies, latencies, bandwidths, etc.
- Flexible use of HPC systems
  Capability- and capacity-computing tasks in both industrial and research environments.
- Seamless integration with multi-disciplinary analyses
  High fidelity CFD tools, interfaces, coupling approaches, etc.

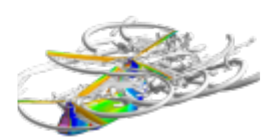








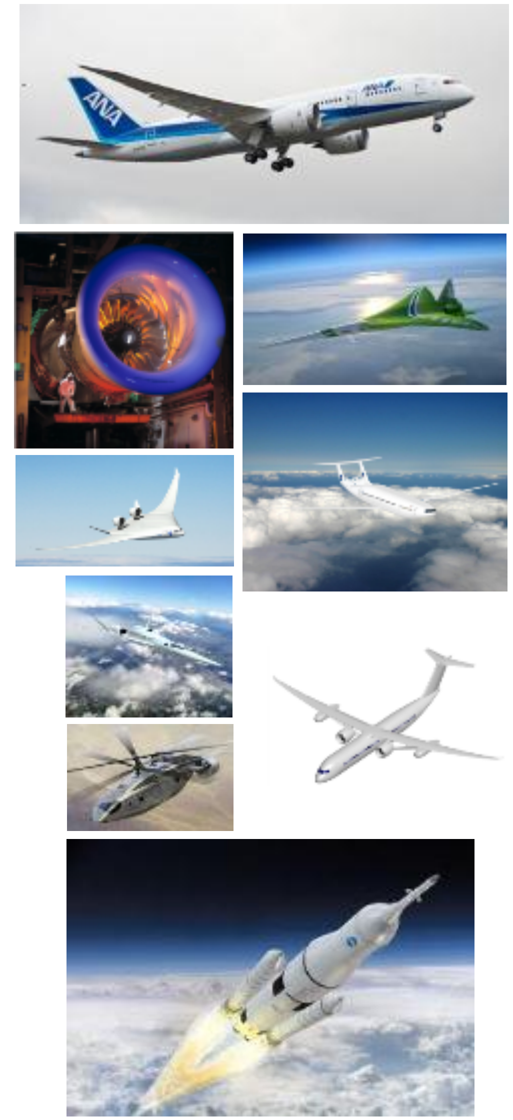




Grand Challenge Problems

- **Represent critical step changes in engineering design capability**
- **May not be routinely achievable by 2030**
- **Representative of key elements of major NASA missions**

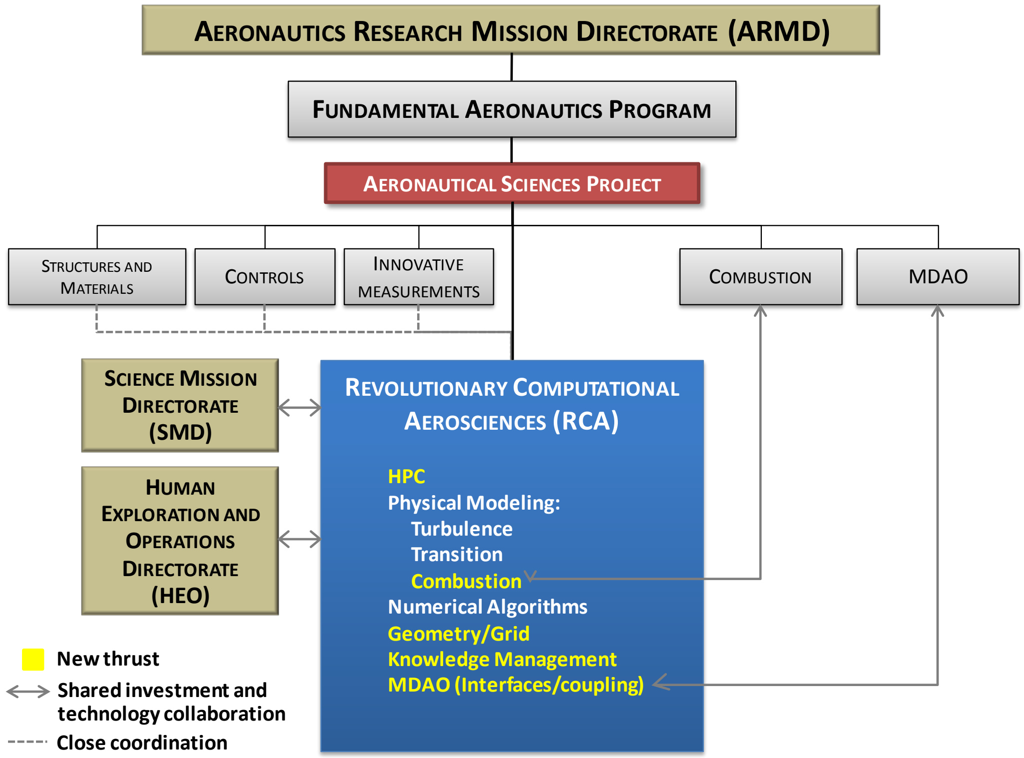
1. Large Eddy Simulation (LES) of a powered aircraft configuration across the full flight envelope
2. Off-design turbofan engine transient simulation
3. Multi-Disciplinary Analysis and Optimization (MDAO) of a highly-flexible advanced aircraft configuration
4. Probabilistic analysis of a powered space access configuration



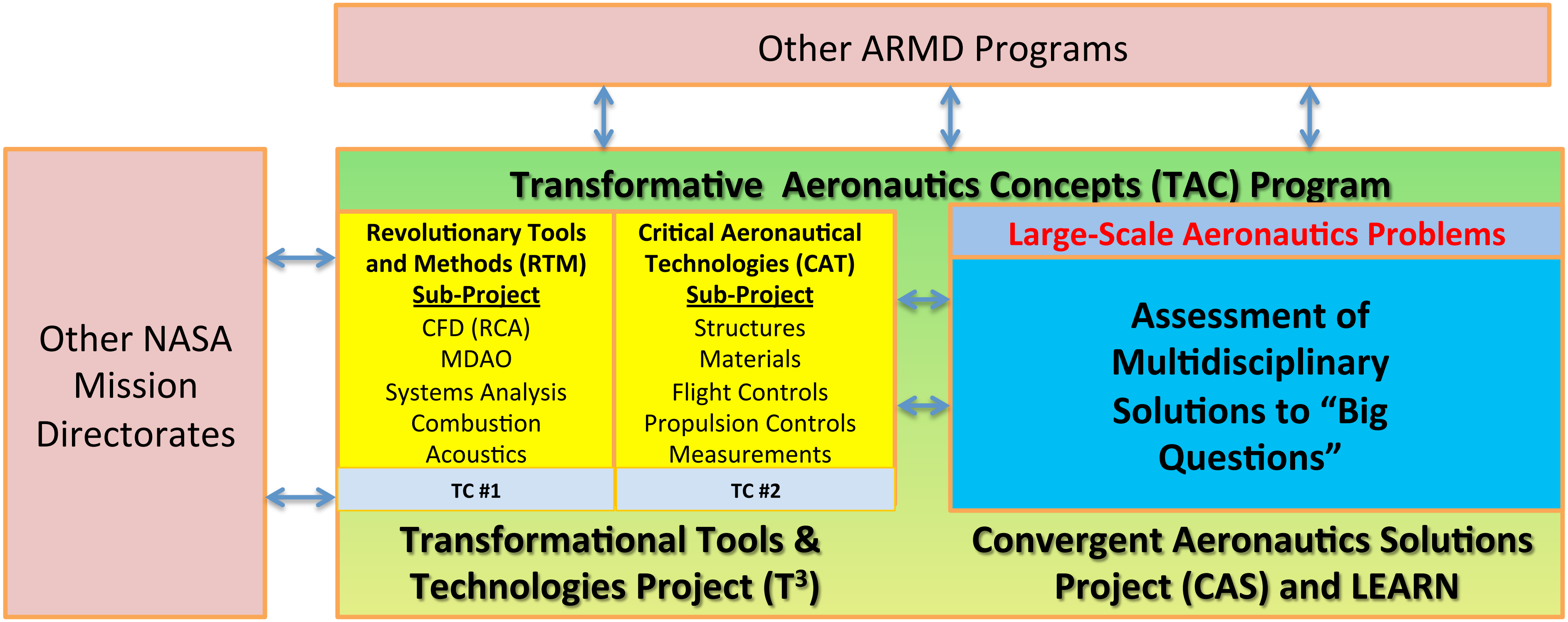
Recommendations

1. **NASA should develop, fund and sustain a base research and technology (R/T) development program for simulation-based analysis and design technologies.**

   - Required to fulfill technology development plan and address Grand Challenge problems
   - RCA program to coordinate ALL key CFD technologies, including combustion and MDAO→ *structured around six technology areas*
   - Success will require collaboration with experts in mathematics, computer science, computational geometry, and other aerospace disciplines



TAC Structure/Connections



T^3 Current and Potential Technical Challenges (red are proposed, subject to discussion)

1: Identify and downselect critical turbulence, transition, and numerical method technologies for 40% reduction in predictive error against standard test cases for turbulent separated flows, evolution of free shear flows and shock-boundary layer interactions on state-of-the-art high performance computing hardware. 2017

1a: Develop validated multidisciplinary analysis methods and tools to enable high-fidelity physics-based modeling and improved design of complex integrated air vehicle systems (How to measure? Against a challenge problem?) 2022

2: Develop high-temperature (2700^{O}F) materials for turbine engines to enable a 6% reduction in fuel burn for commercial aircraft compared to current state-of-the-art materials 2017

2a: Identify, downselect and validate critical fluids, chemistry and structural measurement techniques to substantially increase (3x) spatial and temporal resolution while enabling application to problems relevant for key aeronautics grand challenges. 2020

Aeronautics FY 2015 Budget Request

Aeronautics Research Mission Directorate

($ Millions)

AERONAUTICS	FY 2013 Op Plan	FY 2014 Op Plan	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
	$529.5	**$566.0**	**$551.1**	**$556.6**	**$562.2**	**$567.8**	**$573.5**
Airspace Operations and Safety			131.0	132.7	134.6	135.9	137.3
Advanced Air Vehicles			213.6	211.4	205.8	203.3	205.3
Integrated Aviation Systems			127.0	125.8	128.0	133.4	134.8
Transformative Aeronautics Concepts			79.5	86.8	93.8	95.2	96.2
Aviation Safety	77.6	80.0					
Airspace Systems	89.8	91.8					
Fundamental Aeronautics	167.7	168.0					
Aeronautics Test	74.6	77.0					
Integrated Systems Research	99.0	126.5					
Aeronautics Strategy and Mangt.	21.0	22.7					

Note: As reflected in the August 2013 Operating Plan, FY 2013 includes rescissions per P.L.113-6 Division G, Section 3001(b)(1)(B) and Division G, Section 3004(c)(1) and reductions due to sequestration per BBEDCA Section 215A.

FY 2014 reflects funding amounts specified in P.L. 113-76, Consolidated Appropriations Act, 2014.

AS/TTT Budget Comparison – Year to Year ($K)

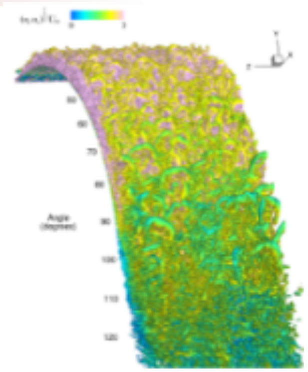
	FY13 Actuals	FY14 Actuals	FY15	FY16	FY17	FY18	FY19	FY20
Total Budget ($K)	$ 33,650	$ 31,798	$ 29,831	$ 33,600	$ 39,415	$ 39,804	$ 39,804	$ 39,804
Labor	$ 20,391	$ 18,693	$ 18,805	$ 21,675	$ 24,457	$ 24,292	$ 25,001	$ 25,731
Travel	$ 271	$ 423	$ 423	$ 423	$ 423	$ 424	$ 424	$ 424
NRA	$ 2,717	$ 3,731	$ 1,300	$ 2,500	$ 2,500	$ 2,500	$ 2,500	$ 2,500
Procurement/Service Pools	$ 10,270	$ 8,951	$ 9,303	$ 9,002	$ 12,035	$ 12,588	$ 11,879	$ 11,149
FTE	138.6	119.4	119.7	133.1	147.9	143.4	143.4	143.4
Not included above			FY15	FY16	FY17	FY18	FY19	FY20
Unallocated Labor			$ -	$ -	$ -	$ -	$ -	$ -
Unallocated FTE			-	-	-	-	-	-

T3 NRA Strategy/Process

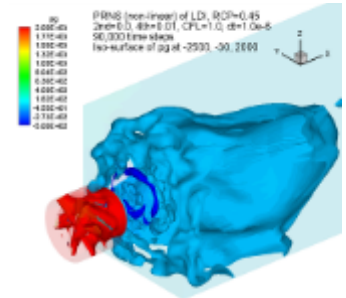
Planned Budget FY16+ 2.5M per year (may bump up in FY17)

- Solicitation Development – Fall 2014
  - Level of Awards – anticipating small awards in T3 (compared to AAVP Projects) – example approach: total 2.5M revealed in solicitation, with quality being the determining factor
  - Gather topics from each discipline area (subprojects – modeling and technology with disciplines within)
  - Prioritize against tech challenges, also integration to ARMD thrusts
  - Plan the insertion path of the NRAs toward T3 studies/content/milestones
- Public Solicitation – Feb 2015
  - NOIs (2 weeks after)
  - Proposals (7 weeks after)
- Reviews – June/July 2015
- Awards/Kickoffs Oct-Nov 2015 (1QFY16)

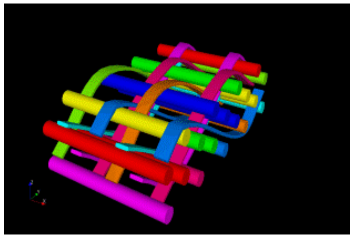
T^3 Project Summary



- Exciting suite of fundamental, cross-cutting, discipline-based research
- Developing and validating critical tools, models and technologies for application to other NASA projects and the broader aeronautics community



- Focused on two major areas – future modeling and design capability and critical innovative technology development
- Leveraging NRA, SAA and SBIR collaborations to augment and complement in-house research efforts



Opportunities ahead with great technologies on the horizon!

http://www.aeronautics.nasa.gov/fap/aeronautical_sciences.html

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